APPENDIX F

DESIGN EXAMPLES—NONBUILDING STRUCTURES

F-1. Introduction. The design examples in this appendix are to illustrate principles, factors, and concepts involved in seismic design. These are not mandatory; and other equivalent methods, materials, or details complying with this manual and applicable agency guide specifications may be used.

F-2. Design Examples—

Fig. No.	*Description of Design Examples*
F-1	*Elevated Tank (Braced Frame).* Four-legged, diagonal braced tower.
F-2	*Vertical Tank (On Ground).* Vertical water tank supported directly by the ground.
F-3	*Horizontal Tank (On Ground).* Typical horizontal tank supported on saddles.
F-4	*Pole-Mounted Transformer.* Equipment supported by a non-building pole structure.
F-5	*Tower-Mounted Equipment.* Tower-supported equipment is investigated for lateral seismic loads. The tower period is computed.

DESIGN EXAMPLE: F-1

ELEVATED TANK (BRACED FRAME):

Description of Structure. A 90,000 gallon steel water tank on top of a 114.5 foot high steel braced frame.

Lateral Loads.

$V = (ZIC/R_w)\ W$ (SEAOC EQ 1-1)

where $Z = 0.3$ (Zone 3)

$I = 1.0$

$R_w = 3$ (SEAOC TABLE 1-I)

$S = 1.5$ (Soil type S_3, SEAOC TABLE 1-B)

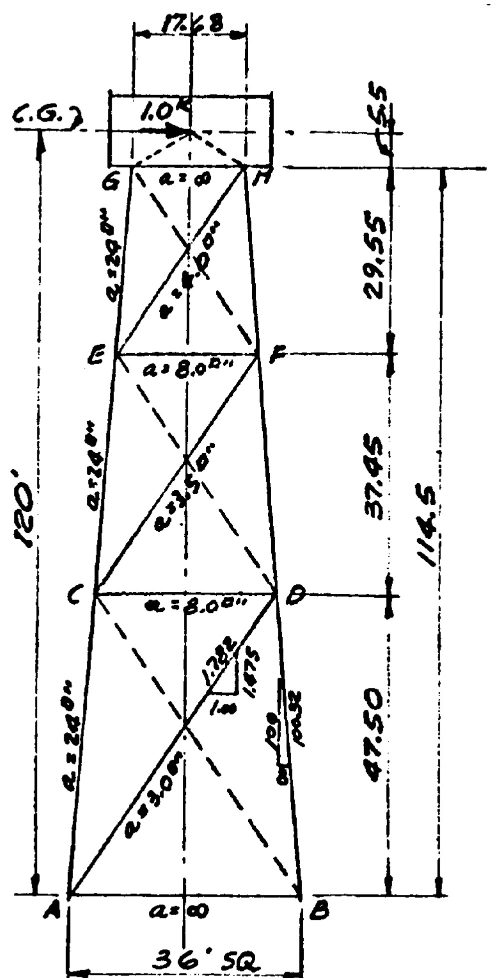
$T = 1.37$ (See Sheet 2)

$C = 1.25\ S/T^{2/3} = 1.52$

$V = (0.3 \times 1.0 \times 1.52/3)\ W = 0.15\ W$

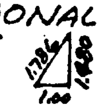
MINIMUM $C/R_w = 0.50$, $V = 0.15W$ (SEAOC 1I 5a)

Figure F-1. Elevated tank (braced frame).



ELEVATION

SLOPE OF DIAGONALS IN PLANE OF SIDE



DEFLECTION Δ*

MEMBER	LENGTH	AREA	u	u^2L/A
A B	36.0	∞	+.134	0
A D	57.5'	3.0"	+.474	4.30
A C	47.8'	24.0	+1.283	3.27
B D	47.8'	24.0	-1.678	5.60
C D	28.4'	8.0	-.296	.31
C F	45.3'	3.5	+.598	4.62
C E	37.7'	24.0	+.787	.97
D F	37.7'	24.0	-1.283	2.58
E F	22.4'	8.0	-.374	.39
E H	35.8'	4.0	+.758	5.14
E G	29.7'	24.0	+.156	.03
F H	29.7'	24.0	-.787	.77
G H	17.68'	∞	-.487	0
				27.98

90,000 GALLON WATER TANK

WEIGHT OF WATER	750^K
STEEL TANK (EST)	72
WATER + TANK	$822^K = W$

NEGLECT WT. OF TOWER

ASSUME BRACES CARRY TENSION ONLY.

COMPUTE THE PERIOD OF THE STRUCTURE TO DETERMINE COEFFICIENTS C AND S

$T = 0.32\sqrt{\frac{W}{K}}$ (EQ 12-1)

$W = 822^K$

K = SPRING CONSTANT (KIPS/INCH)

IF A 1.0^K LATERAL LOAD IS APPLIED AT THE TANK C.G.,

$K = \frac{1.0}{\Delta}$

WHERE Δ = LATERAL DEFLECTION OF TANK DUE TO 1^K LOAD.

$T = 0.32\sqrt{W \times \Delta}$

$\Delta = \frac{2^{*} \times 27.98 \times 12}{30{,}000} = 0.0224$ IN

FOR 1^K LOAD ON TOWER (0.5^K EACH SIDE)

$T = 0.32\sqrt{822 \times 0.0224}$

$= 1.37$ SEC

* 0.5^K APPLIED TO EACH SIDE OF TOWER.
FOR 1.0^K ON THE WHOLE TOWER:

$\Sigma \frac{u^2 L}{A} = 2 \times 27.98$

$\Delta = \Sigma \frac{u^2 L}{AE}$ IN/KIP

Figure F-1. Continued.

V = 0.15 W (SHEET 1 OF 3)

= 0.15 x 822 = 123.3 KIPS.

STRESS IN MEMBERS FOR LOAD APPLIED PARALLEL TO MAJOR AXIS. $V = 123.3^k$

MEMBER		DIRECT LOAD STRESS	ECCEN. LOAD STRESS	TOTAL STRESS	UNIT STRESS
AB	+ .134 x 123.3^k	+ 16.5^k	+ 0.8^k	+ 17.3^k	—
AD	+ .474	+ 58.5	+ 2.9	+ 61.4	20.5 k/□"
AC	+ 1.283	+ 158.2	0.	+ 158.2	6.6
BD	- 1.678	- 207	0.	- 207	8.63
CD	- .296	- 36.5	- 1.8	- 38.3	4.79
CF	+ .598	+ 73.7	+ 3.7	+ 77.4	22.1
CE	+ .787	+ 97.1	0.	+ 97.1	4.05
DF	- 1.283	- 158.2	0.	- 158.2	6.6
EF	- .374	- 46.2	- 2.3	- 48.5	6.06
EH	+ .758	+ 93.4	+ 4.7	+ 98.1	24.5
EG	+ .156	+ 19.2	0.	+ 19.2	0.80
FH	- .787	- 97.1	0.	- 97.1	4.05
GH	- .487	- 60.1	- 3.0	- 63.1	—

STRESSES DUE TO 5% ECCENTRICITY

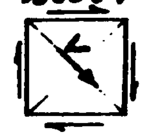
$M_T = .05 \times 36 \times 123.3 = 222^{k'}$

SHEAR ON EA. OF 4 SIDES = $\frac{222}{4 \times 18} = 3.08^k$

STRESS IN WEB MEMBERS = $\frac{3.08}{(123.3/2)}$ x (DIRECT LOAD STRESS)

STRESS IN COLUMNS = 0

.3535 V



CHECK COLUMN FORCES AND UPLIFT FOR LOAD APPLIED AT 45° TO MAJOR AXIS OF TOWER

$$P = \frac{123.3 \times 120}{1.414 \times 36} \times 1.007 = \pm 293 \text{ KIPS}$$

(NOTE: FORCE IN BD x $\sqrt{2}$ = 207 x 1.414 = 293)

GRAVITY FORCE ON COLUMNS = $822^k \div 4$ = -206 KIPS

COLUMN DESIGN: - 293 - 206 = - 499 KIPS (COMPR.)

UPLIFT: + 293 - 0.85 (206)* = 118 KIPS (UPLIFT)

DESIGN ANCHOR BOLTS AND FOUNDATION FOR 118 KIPS UPLIFT FORCE

* REFER TO. SEAOC 1H1b

Figure F-1. Continued.

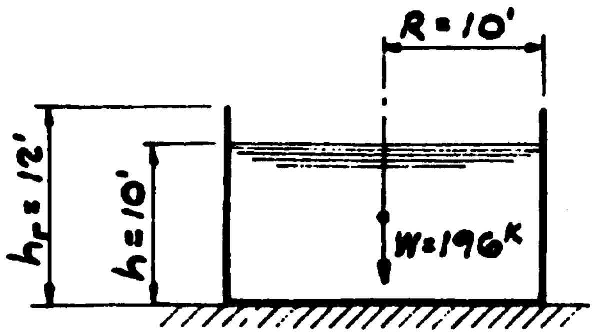
DESIGN EXAMPLE: F-2

VERTICAL TANK (ON GROUND)

Description of Structure. A cylindrical water tank on grade with a radius of 10 feet (R = 10), a height of 12 feet (h_r = 12), and a water depth of 10 feet (h = 10). The tank is located in Seismic Zone 4 and I = 1.0. The weight of the tank is 20 kips.

Required. The period of the sloshing water, the maximum vertical displacement of the water (d_{max}), and the design seismic forces.
Refer to Chapter 13, paragraph 13-4.

Figure F-2. Vertical tank (on ground).



REFER TO FIGURES 13-1 AND 13-2 FOR SEISMIC FORCE DISTRIBUTION

GENERAL

$Z = 0.4$, SEISMIC ZONE 4
$I = 1.0$
$R_w = 4$ (SEAOC TABLE 1-I)
$C = 1.25\, S/T^{2/3} \leq 2.75$ SEAOC EQ 1-2
$S = 1.5$ (NOT KNOWN, SEAOC TABLE 1-B)
$\alpha = h/R = 10.0/10.0 = 1.0$
W (WATER) $= \pi(10)^2(10)(0.0624) = 196^K$
W_r (ROOF) $= 0$ (NO ROOF)
W_w (TANK WALLS) $= 20^K$

Figure F-2. Continued.

RIGID BODY FORCES [PARA. 13-4a (1)]

$V_{RB} = ZIC/R_w\ (W_r + W_W + W_I)$ (13-1)

$C = 2.75$

$ZIC/R_w = 0.4 \times 1.0 \times 2.75/4 = 0.28$

$W_I = 0.54W$ (FOR $\alpha = 1.0$) (TABLE 13-1)
$= 0.54 \times 196 = 106^K$

$V_{RB} = 0.28\,(0 + 20 + 106) = \underline{35.3^K}$

$h_I = 0.38h$ (TABLE 13-2)
$= 0.38 \times 10 = 3.8$ FT.

$h_I' = 0.80h$ (TABLE 13-2)
$= 0.80 \times 10 = 8.0$ FT

M_{RB} (TANK SHELL) $= ZIC/R_w\ [W_r h_r + W_W \bar{h}_W + W_I h_I]$ (13-2)
$= 0.28\left[0 + 20\left(\frac{12}{2}\right) + 106(3.8)\right]$
$= \underline{146^{K\text{-}FT}}$

M_{RB} (BELOW BASE) $= 0.28\left[0 + 20\left(\frac{12}{2}\right) + 106(8.0)\right]$
$= \underline{271^{K\text{-}FT}}$

Figure F-2. Continued.

SLOSHING WATER FORCE [PARA. 13-4a (2)]

PERIOD, $T = k_T\sqrt{h}$ (13-4)

$k_T = 0.84$ (TABLE 13-3)

$T = 0.84\sqrt{10} = \underline{2.66 \text{ SEC.}}$

$V_{SL} = (ZIC/R_w)W_c$ (13-3)

$C = 1.25\ S/T^{2/3} = 0.97$

$S = 1.5$ (MAXIMUM VALUE)

$ZIC/R_w = 0.4 \times 1 \times 0.97 \times 1/4 = 0.097$

$W_c = 0.43W$ (TABLE 13-1)

$= 0.43 \times 196 = 84.3^K$

$V_{SL} = 0.097 \times 84.3 = \underline{8.2^K}$

$h_c = 0.60h = 0.60 \times 10 = 6.0$ FT. (TABLE 13-2)

$h'_c = 0.79h = 0.79 \times 10 = 7.9$ FT.

M_{SL} (TANK SHELL) $= (ZIC/R_w)W_c\, h_c$ (13-5)

$= 0.097 \times 84.3 \times 6.0$

$= \underline{49.1^{K\cdot FT}}$

M_{SL} (BELOW BASE) $= 0.097 \times 84.3 \times 7.9$

$= \underline{64.6^{K\text{-}FT}}$

Figure F-2. Continued.

HEIGHT OF SLOSHING WATER

$$d_{MAX} = \left[\frac{0.75\,(ZIC/R_w)}{1-k_d(ZIC/R_w)}\right]R \qquad (13\text{-}6)$$

$$= \left[\frac{0.75\,(0.097)}{1-(1.75)(0.097)}\right]10.0 \qquad (k_d \text{ FROM TABLE 13-4})$$

$$= \underline{\underline{0.88 \text{ FT.}}} \quad (\text{LESS THAN } h_r - h = 2 \text{ FT, OK})$$

TOTAL DESIGN FORCES [PARA. 13-4a(3)]

$$V_{TOTAL} = \sqrt{V_{RB}^2 + V_{SL}^2} \qquad (13\text{-}8)$$

$$= \sqrt{(35.3)^2 + (8.2)^2} = \underline{\underline{36.2^K}}$$

$$M_{TOTAL} = \sqrt{M_{RB}^2 + M_{SL}^2} \qquad (13\text{-}9)$$

$$\text{FOR TANK SHELL} = \sqrt{146^2 + 49.1} = \underline{\underline{154^{K\cdot FT}}}$$

$$\text{FOR BELOW BASE} = \sqrt{271^2 + 64.6^2} = \underline{\underline{279^{K\cdot FT}}}$$

Figure F-2. Continued.

DESIGN EXAMPLE: F-3

HORIZONTAL TANK (ON GROUND):

Description of Structure. A 20,000 gallon steel tank in concrete saddles on a concrete slab on grade. Seismic Zone 2A, I = 1.0, S = 1.5 For this rigid structure $T \leq 0.3$ sec.

Lateral Loads:

$$V = \frac{ZIC}{R_W} W$$

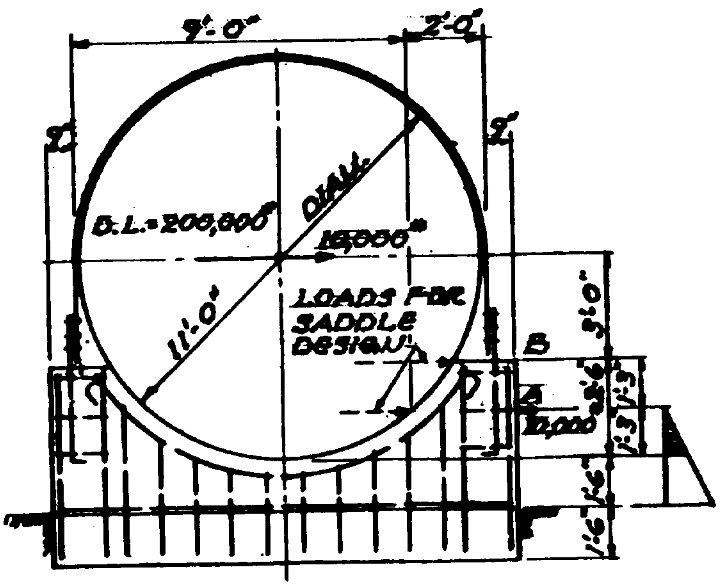
where $Z = 0.15$, $I = 1.0$, $R_W = 4$, $S = 1.5$
$C = 2.75$ (Table 4-1)
W = Weight of Tank plus contents.

$$V = \frac{0.15(1.0)(2.75)}{4} W$$

$$= 0.10\ W > 0.075\ W \quad \text{(OK)}$$

[MINIMUM $C/R_W = 0.5$; $V = 0.15 \times 0.5W = 0.075W$ (SEAOC 1I5a)]

Figure F-3. Horizontal tank (on ground).



20,000 GALLON TANK
11'-0" DIAM. x 28'-0" LONG
WEIGHT TANK PLUS
CONTENTS 200,000 LBS.
SEISMIC LATERAL FORCE
$V = 0.10\,W$
$= 0.10 \times 200,000$
$= 20,000$ LB.
OR 10,000 LB. EA. SADDLE

STRAP DESIGN:

FOR THE PURPOSE OF THIS EXAMPLE ASSUME THE REACTION IS AT LEVEL "A" AND NEGLECT WEIGHT OF TANK AND CONTENTS.

$M = 10000 \times 4.25 = 42,500'\#$

STRESS $= 42,500/9.0 = 4,720\#$ IN STRAP.

SADDLE DESIGN

FOR REINFORCEMENT ASSUME THE LOAD ON THE PIER TO BE APPLIED AT LEVEL "B"

MOMENT WITH LOAD APPLIED AT LEVEL B

$M = 10,000 \times 2.5 = 25,000'\#$ DESIGN REINF. TO RESIST THIS BENDING MOMENT IN ACCORDANCE WITH STANDARD PROCEDURE.

BASE DESIGN

TOTAL O.T.M. $= 20,000 \times 8.5 = 170,000'\#$

BASE $12'\text{-}6" \times 24'\text{-}0"$ $A = 12.5 \times 24 = 300\square'$

SECTION MODULUS $S = \frac{24 \times (12.5)^2}{6} = 625$

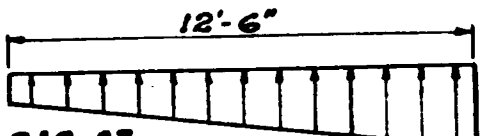
EA. SADDLE $= 5880\# \times 2 =$ $11,760\#$

BASE WEIGHT $= 225 \times 300 = 67,500\#$

$+200,000$

$279,260\#$ TOTAL WEIGHT

$$\frac{P}{A} = \frac{279,260}{300} = 930.87 \quad \frac{M}{S} = \frac{170,000}{625} = 272$$

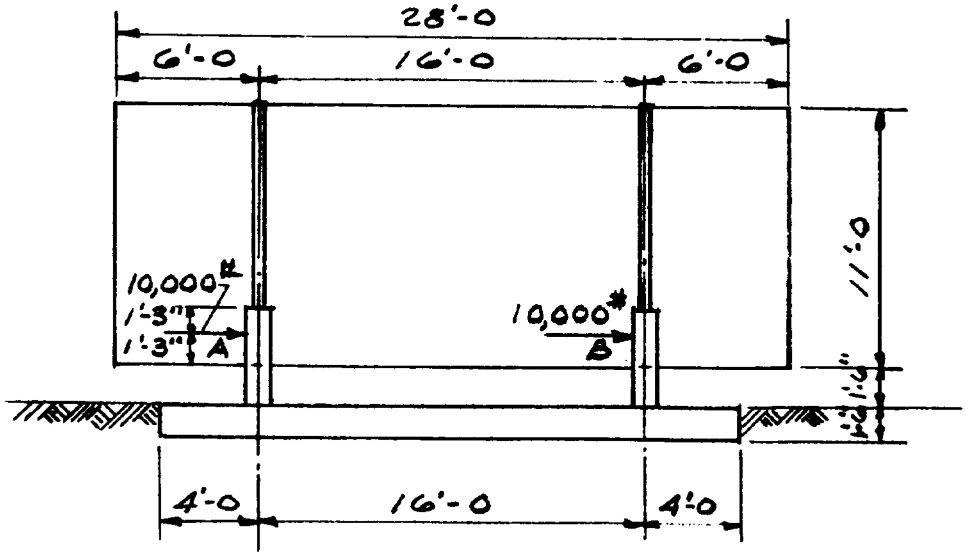


930.87
$+272.0$
$1202.87\#/\square'$

930.87
-272.0
$658.87\#/\square'$

RESULTANT IS IN MIDDLE THIRD

Figure F-3. Continued.



OVERTURNING ON SUPPORT IS NEGLIGIBLE AND IS NOT INCLUDED IN THIS CALCULATION

SADDLE DESIGN

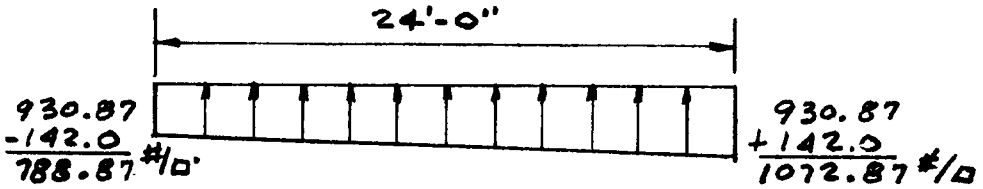
$M_A = M_B$ ABOUT BASE OF TANK = 10,000 × 1.25 = 12,500'#
ABOUT FOOTING = 10,000 × 2.75 = 27,500'#
DESIGN REINF. TO RESIST THESE BENDING MOMENTS IN ACCORDANCE WITH STANDARD PROCEDURE

BASE DESIGN

DESIGN REINF. IN FOOTING IN ACCORDANCE WITH STANDARD PROCEDURE TO RESIST SADDLE M = 27,500'#
TOTAL O.T.M. = 20,000 × 8.5 = 170,000'#

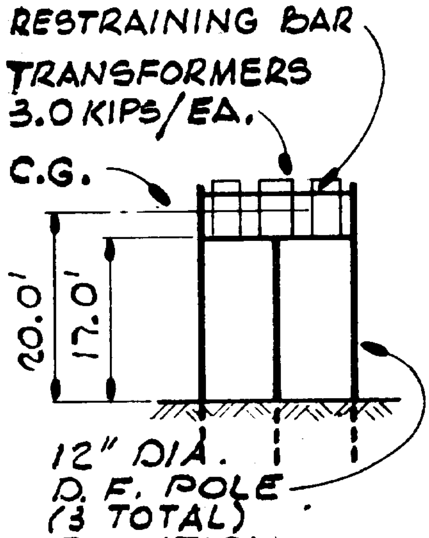
SECTION MODULUS $S = \frac{12.5 \times (24)^2}{6} = 1200$

$\frac{P}{A} = 930.87$ (FROM SHEET 2 OF 3) $\frac{M}{S} = \frac{170,000}{1200} = 142$



RESULTANT IS IN MIDDLE THIRD
DESIGN FOOTING FOR SOIL PRESSURES SHOWN IN ACCORDANCE WITH STANDARD PROCEDURE.

Figure F-3. Continued.



GIVEN:

WT. TRANSFORMERS = 3.0 KIPS / EA.
WT. POLES = 35 LB/FT./POLE
E (POLES) = 1.6×10^6 LB/IN.^{2}
SOIL PROPERTIES ARE UNKNOWN
ASSUME EACH POLE ACTS AS A 20' LONG CANTILEVER
SEISMIC ZONE 3 OCCUPANCY CATEGORY 1 (ESSENTIAL FACILITY).

REQUIRED:

FIND THE SEISMIC FORCE COEFFICIENT FOR THE WEAK AXIS OF THE POLE FRAME. (I.E., NORMAL TO THE PAPER.)

SOLUTION:

CLASSIFY AS A NON-BUILDING STRUCTURE.

$$T = 0.32\sqrt{\frac{W}{k}} \qquad \text{(EQ 12-1)}$$

$$W = 3000 + \frac{35 \times 20}{2} = 3{,}350 \text{ LB/POLE}$$

CALCULATION OF k:

$$I_o \text{ (ONE POLE)} = .785R^4 = .785(6)^4 = 1017 \text{ IN.}^4$$

$$\Delta = \frac{PL^3}{3EI_o} \quad \text{OR} \quad k = \frac{3EI_o}{L^3} = \frac{3(1.6 \times 10^6(1017)}{(20 \times 12)^3}$$

$$= 353 \text{ LBS/IN.}$$

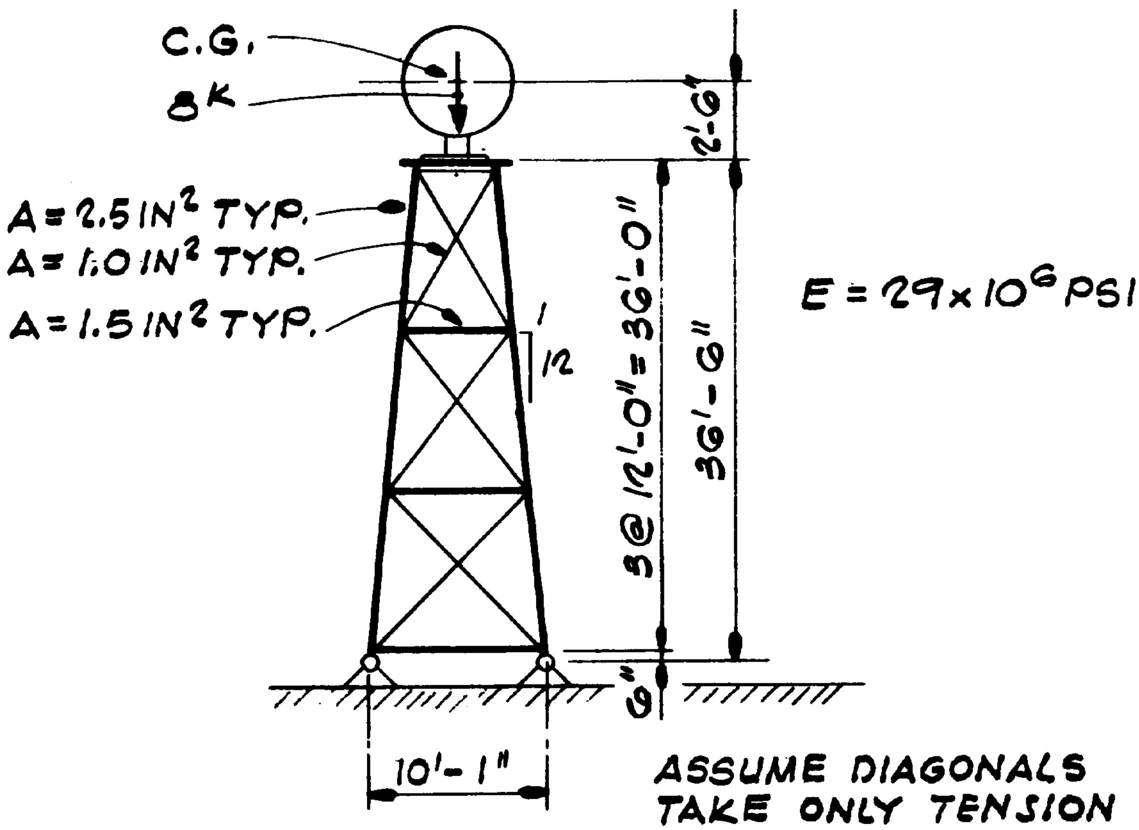
$$\therefore T = 0.32\sqrt{\frac{3350}{353}} = 0.99 \text{ SEC.}$$

$V = (ZIC/R_w)W$ (SEAOC EQ 1-1)
$Z = 0.30$ (ZONE 3)
$I = 1.25$ (ESSENTIAL FACILITY)
$R = 3$ (INVERTED PENDULUM) SEAOC TABLE 1-I
$C = 1.88$ (TABLE 4-1 FOR $T = 1.0$ SEC)
$C/R_W = 1.88/3 = 0.63 > 0.50$ (SEAOC 1I5a)
$V = (0.30 \times 1.25 \times 1.88/3)\,W = \underline{\underline{0.236\,W}}$

Figure F-4. Pole-mounted transformer.

GIVEN :

MISSILE TRACKING DEVICE SITUATED ON TRUSS TOWER: SEISMIC ZONE 2B
ESSENTIAL FACILITY
SITE TYPE S_3



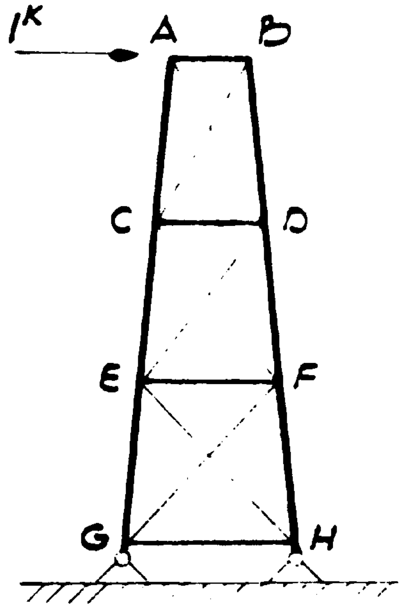
REQUIRED :

FIND THE LATERAL SEISMIC FORCE TO BE APPLIED AT THE CENTER OF GRAVITY OF THE TRACKING DEVICE. CLASSIFY AS RIGID EQUIPMENT ON A STRUCTURE OTHER THAN A BUILDING.

Figure F-5. Tower-mounted equipment.

SOLUTION :

MEMBER	P FORCE (KIPS)	L (IN.)	A (IN.^{2})	$\frac{P^2L}{A}$
AB	1.00	48	∞	0
AC	0	145	2.5	0
AD	0	156	1.0	0
BC	+2.17	156	1.0	734.6
BD	-2.02	145	2.5	236.6
CD	-0.67	72	1.5	21.5
CE	+2.02	145	2.5	236.6
CF	0	167	1.0	0
DE	+1.16	167	1.0	224.7
DF	-3.02	145	2.5	529.0
EF	-0.50	96	1.5	16.0
EG	+3.02	145	2.5	529.0
EH	0	180	1.0	0
FG	+0.75	180	1.0	101.8
FH	-3.63	145	2.5	764.3
GH	+0.30	120	1.5	7.2



NOTE: PT. H IS ASSUMED TO TAKE NO BASE SHEAR AS MEMBER EH CARRIES NO LOAD

$$1^K \cdot \frac{\Delta}{2} = \sum \frac{P^2L}{2AE} \; ; \; \sum \frac{P^2L}{A} = 3401.3 \ K^2/IN.$$

$$\sum \frac{P^2L}{AE} = 1.17 \times 10^{-1} = 0.117 \text{ INCHES/KIP}$$

$$\left(\frac{1}{\Delta}\right) = k \quad k = 8.55 \text{ KIPS/IN. PER SIDE}$$

$$T = 0.32\sqrt{\frac{W}{k}} = 0.32\sqrt{\frac{8.0}{2(8.55)}} = 0.22 \text{ SEC (EQ 12-1)}$$

$Z = 0.20$ (ZONE 2B), $I = 1.25$ (ESSENTIAL FACILITY)

$R_w = 3.0$ (INVERTED PENDULUM), $C = 2.75$ (TABLE 4-1)

$V = (ZIC/R_w)W = (0.20 \times 1.25 \times 2.75/3)W = 0.23 \times 8 = 1.84$ KIPS

NOTE: WEIGHT OF TOWER WAS NEGLECTED.

Figure F-5. Continued.